

## NOTES ON STAUROLITE FROM THE MOGUMBER DISTRICT.

By EDWARD S. SIMPSON, D.Sc., B.E., F.C.S.

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Staurolite,  $\text{H}(\text{Fe}, \text{Mg})(\text{Al}, \text{Fe})_5\text{Si}_2\text{O}_{13}$ , is a comparatively rare metamorphic mineral hitherto recorded from but few localities in Australia. Anderson, in his *Bibliography of Australian Mineralogy*, gives no locality for it in Victoria, Northern Territory or Tasmania, one only in New South Wales, and two each in Queensland and South Australia.

The existence of this mineral in a belt of country lying somewhere to the north-east of Gingin has been known since 1915, when a parcel of small (4 to 10 mm.) crystals collected from gravel in the valley of Chittering Brook (Brockman River) were submitted to the writer for determination. The more perfect of these showed a combination of the faces  $m^1(110)m^2m^3m^4b^1(010)b^2$ . There were imperfect indications of occasional twinning on  $z(232)$ .

Later, in 1917, a single large water-worn crystal was seen which was said to have come from about 13 miles N.E. of Gingin, *i.e.*, between Cullalla and Wannamal, and not far from the head of Chittering Brook, Mogumber being about 22 miles N.N.E. of Gingin. This crystal was a combination of  $m^1(110)m^2m^3m^4b^1(010)b^2c^1(001)$ . It was 5 cm. in length with a maximum diameter of 4.5 cm. From the same locality came a boulder of rock composed of granular quartz and staurolite, the latter predominating, and occurring in grains of about 1 mm. diameter.

Last year was seen for the first time the probable matrix from which these loose crystals were derived. This is a rock found between Mogumber and Gillingarra. It is fairly uniform in texture, consisting of a ground mass of small scales of muscovite and grains of quartz, in which are embedded numerous large crystals of staurolite and biotite. Of the two coarser constituents staurolite is by far the more common, and is rather evenly distributed throughout this particular specimen. It is in prismatic crystals of a dark brown colour ranging from 1 to 5 millimetres in diameter, and 5 to 30 millimetres in length. The larger sized crystals are infrequent. Twinning has been observed on  $z(232)$  but is rare.

Quite recently a fine suite of specimens of this rock was obtained. These are of the same general type as that just described,

but many of the staurolite crystals are much larger, reaching 2 cm. in diameter and 5 cm. in length. The matrix is seen under the microscope to be mainly muscovite in moderately coarse flakes with minor amounts of quartz, chlorite and biotite. Small granules of a black iron ore are abundant and occasional very large biotite crystals. The embedded staurolite crystals show the typical pronounced pleochroism from pale yellow (X,Y) to reddish brown (Z), with high refractive index and biaxial figure. The smaller staurolites (2 mm.) in the section cut are mostly quite free from inclusions, but some carry a large number of the black iron ore granules. The total lack of quartz inclusions is unusual, as Van Hise draws attention to "the absence of inclusions of the iron-bearing constituents of the schists in garnet and staurolite, and the presence of abundant quartzose particles."\*

Macroscopically the staurolite is seen to be dark brown in colour, well crystallised, and of all sizes, from 1 to 20 mm. in diameter, some crystals being short and stout, others long and thin. The faces  $m^1(110)m^2m^3m^4b^1(010)b^2$  are seen on all, and  $r^1(101)r^2$  on many. Twins on  $z(232)$  are fairly common even with the largest crystals. The measured angles  $b^1m^1, m^1m^4, m^4r^1$ , and  $r^1r^2$  agree closely with those calculated. A cleavage parallel to  $b$  is distinct.

The staurolite is very unevenly distributed through the rock and is without definite orientation.

Regarding the origin of the Mogumber staurolite: This mineral is usually developed by thermal metamorphism of a non-calcareous sediment at a high pressure but comparatively low temperature, as indicated by the combined water present. Chloritoid, a mineral very similar in composition and origin to staurolite, is found in nature under practically identical conditions. The causes which lead to the formation of the one mineral rather than the other have not yet been explained, and can only be elucidated by a close study of the occurrences of both minerals. Other closely related metamorphic minerals are garnet and chlorite. Van Hise says of the origin of staurolite (Metamorphism, p. 327):—

"Staurolite is similar in its occurrence to garnet, but apparently requires more intense metamorphic action for it to begin to form. Its most widespread occurrence is in the schists and gneisses of sedimentary origin. It also develops in profoundly metamorphosed rocks of eruptive origin, but it is not known as an original constituent in any eruptive rock. Like garnet, it may be abundantly developed in the zone of anamorphism in rocks which are cut by intrusives. The conditions favourable to its formation are therefore similar to those which produce garnet (see pp. 300-302) and such minerals as tourmaline, andalusite, sillimanite, and cyanite, with

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\* Treatise on Metamorphism, p. 701.

which it is associated. It is evidently a mineral which derives its materials from various other minerals, the elements being re-combined into the more compact form of staurolite under deep-seated conditions."

The densities and compositions of the four genetically related minerals Prochlorite, Chloritoid, Staurolite, and Almandine, are:—

Mineral.	Composition.	Water. %	Density.	Molecular* Volume.
Prochlorite	$x\ 2\text{H}_2\text{O} \cdot 3(\text{Fe, Mg})\text{O} \cdot 2\text{SiO}_2 +$ $y\ 2\text{H}_2\text{O} \cdot 2(\text{Fe, Mg})\text{O}(\text{Al, Fe})_2\text{O}_3 \cdot$ $\text{SiO}_2$	10-12	2.95	114†
Chloritoid ...	$\text{H}_2\text{O} \cdot (\text{Fe, Mg})\text{O} \cdot (\text{Al, Fe})_2\text{O}_3 \cdot$ $\text{SiO}_2$	6-7	3.55	69
Staurolite ...	$\text{H}_2\text{O} \cdot 2(\text{Fe, Mg})\text{O} \cdot 5(\text{Al, Fe})_2\text{O}_3 \cdot$ $4\text{SiO}_2$	1-2	3.70	122 (or 244)
Almandine ...	$3(\text{Fe, Mg})\text{O} \cdot (\text{Al, Fe})_2\text{O}_3 \cdot$ $3\text{SiO}_2$	none	4.05	117

From these figures one is led to the conclusion that temperature and pressure play a large part in determining which species is generated by the metamorphism of a given rock containing the materials required. It is evident that at the lowest temperatures and pressures prochlorite would tend to form; at higher temperatures but moderate pressures, staurolite. On the other hand, at high pressures and moderate temperatures, chloritoid would develop, whilst at the highest temperatures with moderately low pressures, almandine garnet would form. See Plate XIII.

The data for lolite, a very similar mineral found both in igneous and metamorphic rocks, are imperfect. Its water percentage may be 1.5 or nil, and its molecular volume 227, 232 or 465. These figures point to a fairly high temperature and very low pressure as the condition conducive to its formation.

Staurolite in hand specimens has now been recorded from the following localities in the State: Mogumber and Greenbushes (S.W. Division), Mondoo<sup>na</sup>, Mary River and Richenda River (Kim. Div.). In addition, microscopic grains have been observed in heavy sands from several localities in the South-Western Division, including Freshwater Bay, Cape Leeuwin, Pemberton and Cheyne's Bay.

\* Based on a constant ratio for all four minerals of three Fe" to one Mg, and on the assumption that the usual proportion of Fe''' is negligible.

† Van Hise's data for prochlorite, on p. 196 of his *Metamorphism*, require revision. His molecular weight 1,382.52 seems to be based on two wrong assumptions, *viz.*, (1) that MgO is the only protoxide present, whereas as a matter of fact FeO and MgO are usually present in about equal molecular proportions, (2) that the empirical formula, copied from Tschermak, contains only two molecules, whereas it contains three of serpentine and seven of amesite, a total of ten. These molecules are not additive but substitutive. The true molecular weight is therefore in the vicinity of 318, varying with the relative ratios of Mg to Fe, and of Sp to At. His density 2.71 is too low, judging by the figures given by Dana; 2.85 appears to be a better figure for a unit ratio of Fe to Mg. Finally, his molecular volume, 509.216 is approximately five times too high, being dependent on the molecular weight and on the inverse of the density. Taking 318 for M.W. and 2.85 for density, the M.V. is 112.

*Addendum.*—Whilst the above was being written analyses of the clean staurolite and of the staurolite-bearing rock from Mogumber were in progress. These were subsequently completed with the following results:—

				Staurolite.		Staurolite Schist.
				%		%
SiO <sub>2</sub>	...	...	...	29·12	...	40·81
Al <sub>2</sub> O <sub>3</sub>	...	...	...	52·47	...	30·69
Fe <sub>2</sub> O <sub>3</sub>	...	...	...	?	...	4·37
FeO	...	...	...	13·89	...	5·86
MnO	...	...	...	·22	...	·10
MgO	...	...	...	2·64	...	5·52
CaO	...	...	...	·18	...	·15
Na <sub>2</sub> O	...	...	...	...	...	·88
K <sub>2</sub> O	...	...	...	...	...	6·58
H <sub>2</sub> O—	...	...	...	...	...	·09
H <sub>2</sub> O+	...	...	...	1·46	...	3·98
TiO <sub>2</sub>	...	...	...	·82	...	·90
P <sub>2</sub> O <sub>5</sub>	...	...	...	...	...	·08
S	...	...	...	...	...	<i>Nil</i>
				100·80		100·01
Sp. gr....				3·76		2·91

Two kilograms of the rock were sampled down for the rock analysis, and a clean crystal free from inclusions and weighing 8·3 grams was taken for the mineral analysis. Neither Grubenmann, Zirkel nor Clarke gives any analysis of a staurolite schist with which to compare the figures for the Mogumber rock.

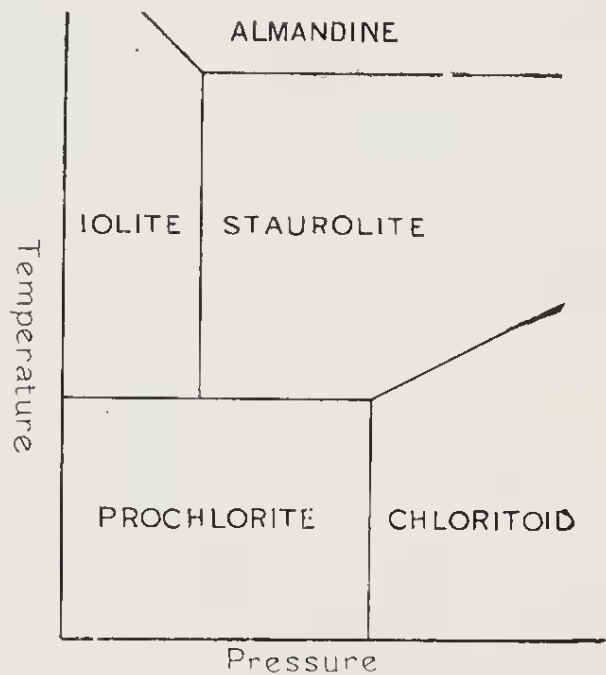


Plate X.—Diagram illustrating the physical conditions conducive to the formation of the Prochlorite-Almandine Series.